



US006700752B2

(12) **United States Patent**
Dimitrov et al.

(10) **Patent No.:** **US 6,700,752 B2**
(45) **Date of Patent:** **Mar. 2, 2004**

(54) **NON-MAGNETIC METALLIC LAYER IN A READER GAP OF A DISC DRIVE**

(56) **References Cited**

(75) Inventors: **Dimitar Dimitrov**, Edina, MN (US); **Michael C. Kautzky**, Eagan, MN (US); **Sunita B. Gangopadhyay**, Chanhassen, MN (US); **Jumna P. Ramdular**, deceased, late of Brooklyn Park, MN (US), by Ruperta Ramdular, legal representative; **Sisavath M. Bounnakhom**, Savage, MN (US); **I-Fei Tsu**, Bloomington, MN (US); **Robert W. Lamberton**, Londonderry (GB)

(73) Assignee: **Seagate Technology LLC**, Scotts Valley, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 41 days.

(21) Appl. No.: **10/107,990**

(22) Filed: **Mar. 27, 2002**

(65) **Prior Publication Data**

US 2002/0154451 A1 Oct. 24, 2002

Related U.S. Application Data

(60) Provisional application No. 60/284,624, filed on Apr. 18, 2001.

(51) **Int. Cl.**⁷ **G11B 5/33**

(52) **U.S. Cl.** **360/317; 360/126**

(58) **Field of Search** 360/317, 320, 360/319, 123, 126, 318, 125; 29/603.13, 603.14, 603.2; 228/215

U.S. PATENT DOCUMENTS

5,739,990 A	4/1998	Ravipati et al.	360/113
5,883,764 A	3/1999	Pinarbasi	360/113
5,898,548 A *	4/1999	Dill et al.	360/319
5,958,612 A	9/1999	Saito et al.	428/692
6,018,862 A	2/2000	Stageberg et al.	29/603.14
6,195,232 B1 *	2/2001	Cohen	360/123
6,198,608 B1 *	3/2001	Hong et al.	360/320
6,212,047 B1	4/2001	Payne et al.	360/318.1
6,375,063 B1 *	4/2002	Basra et al.	228/215
6,396,670 B1 *	5/2002	Murdock	360/319
6,400,537 B2 *	6/2002	Sakakima et al.	360/319
6,404,603 B1 *	6/2002	Inoue et al.	360/320

* cited by examiner

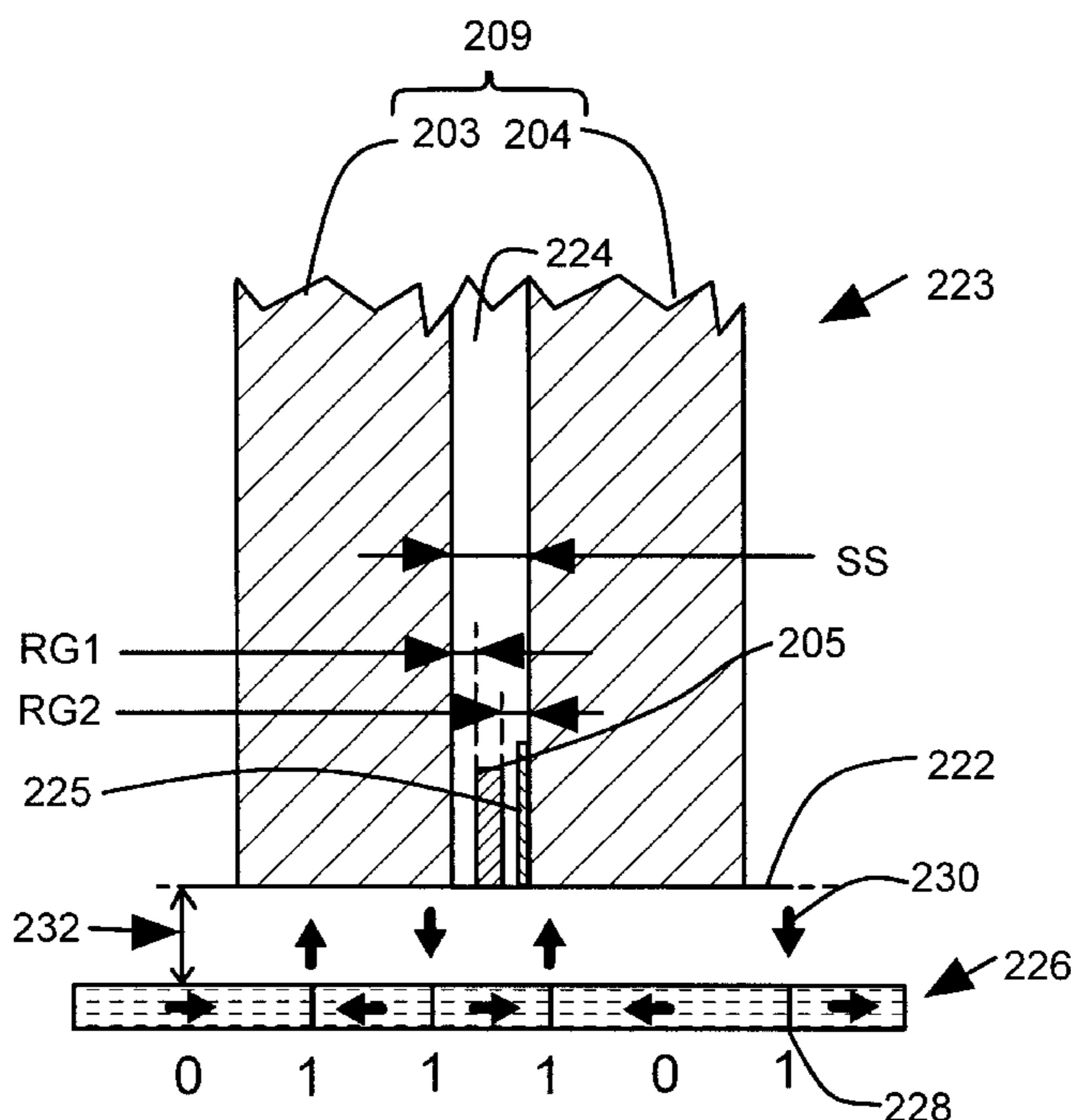
Primary Examiner—Tianjie Chen

(74) *Attorney, Agent, or Firm*—Westman, Champlin & Kelly

(57) **ABSTRACT**

A read/write head with a bottom shield on a slider substrate and a shared shield spaced apart from the bottom shield. A write head is deposited on the shared shield. A read sensor is spaced apart by reader magnetic gaps from the bottom shield and the shared shield. Electrically insulating layers in the reader magnetic gaps form a thermal resistance between the read sensor and the shields. A thermally conducting nonmagnetic layer in a reader magnetic gap reduces the thermal resistance without a corresponding reduction in the reader magnetic gaps.

9 Claims, 8 Drawing Sheets



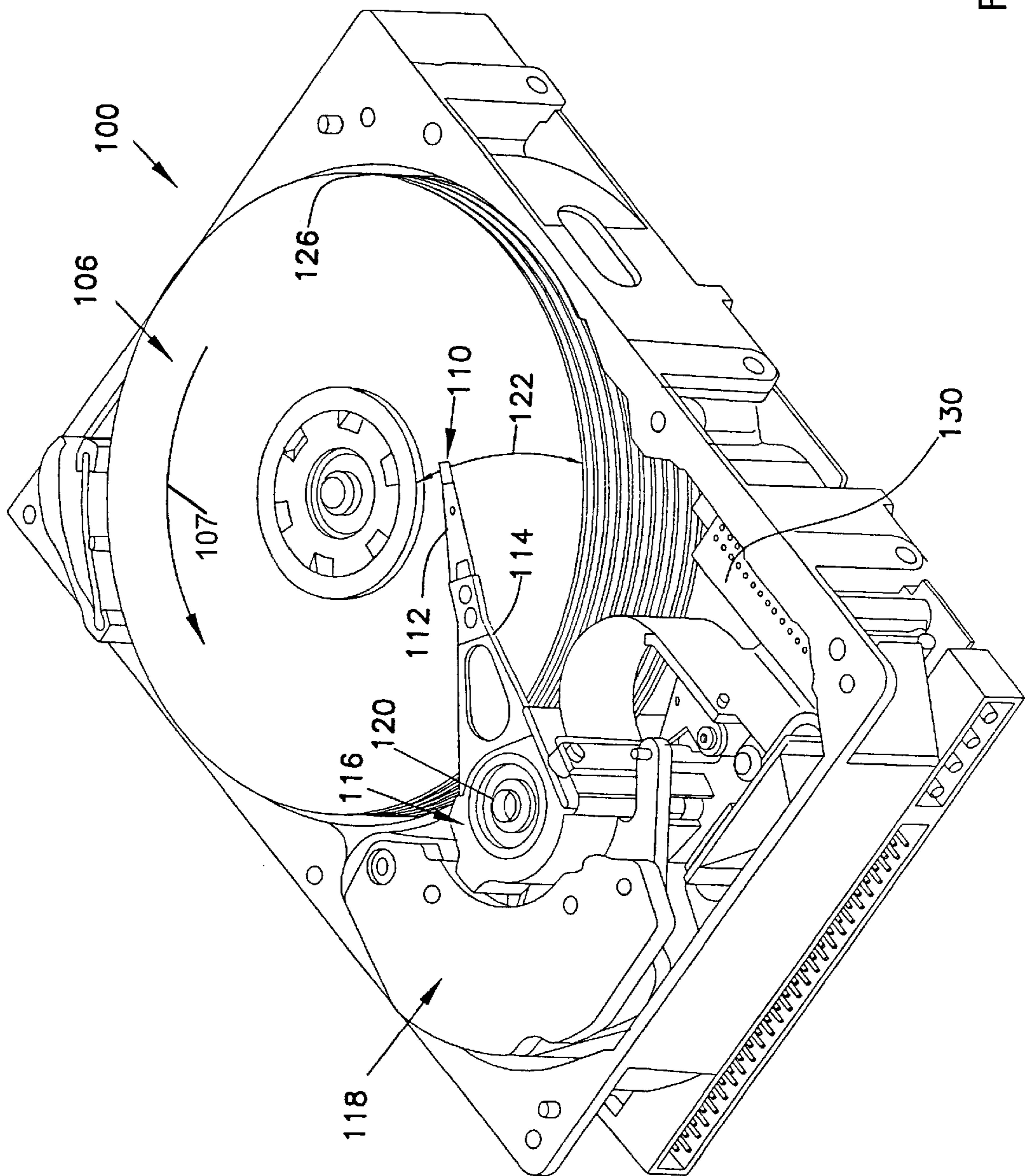
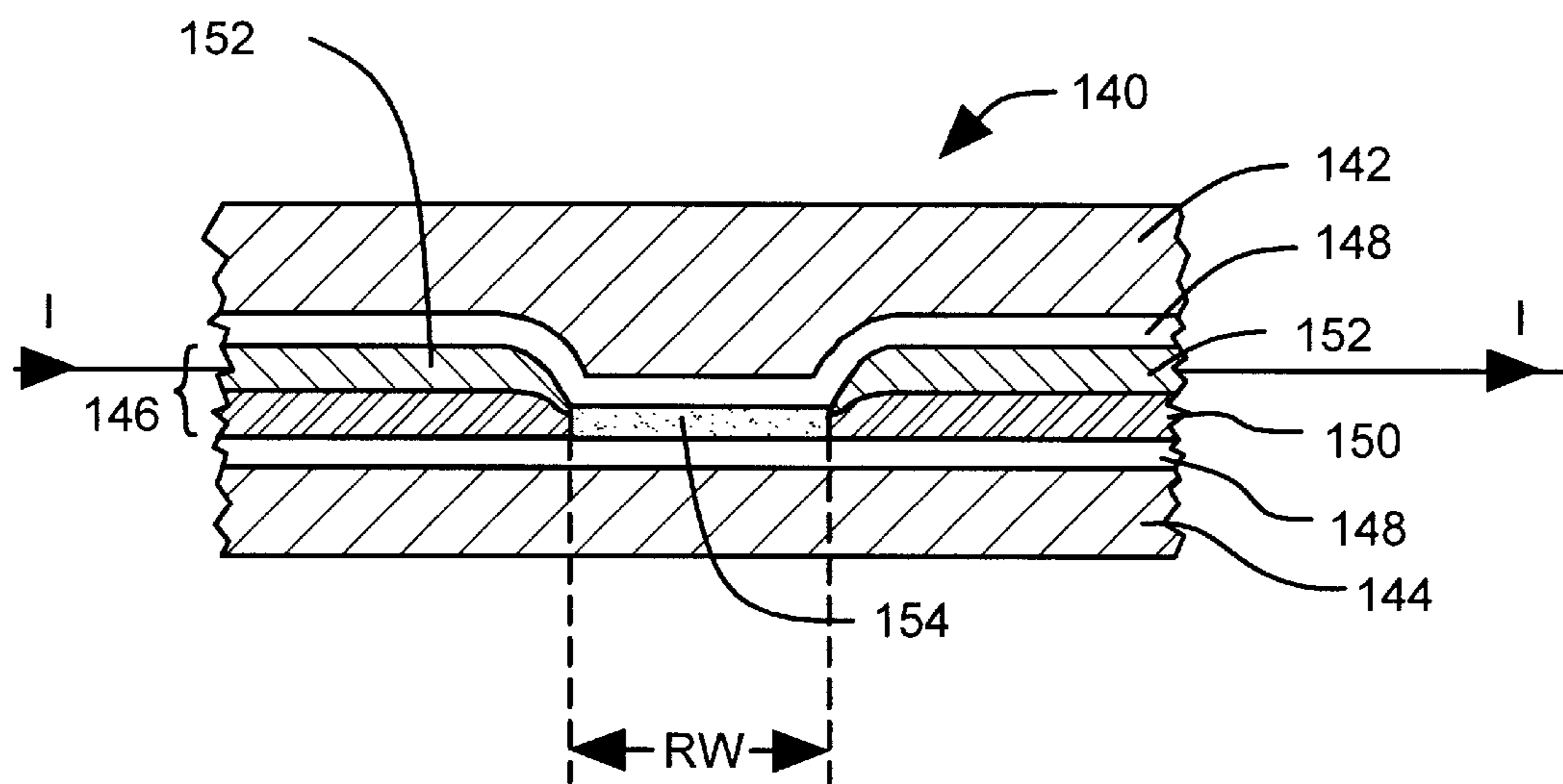


FIG. 1



PRIOR ART
FIG. 2

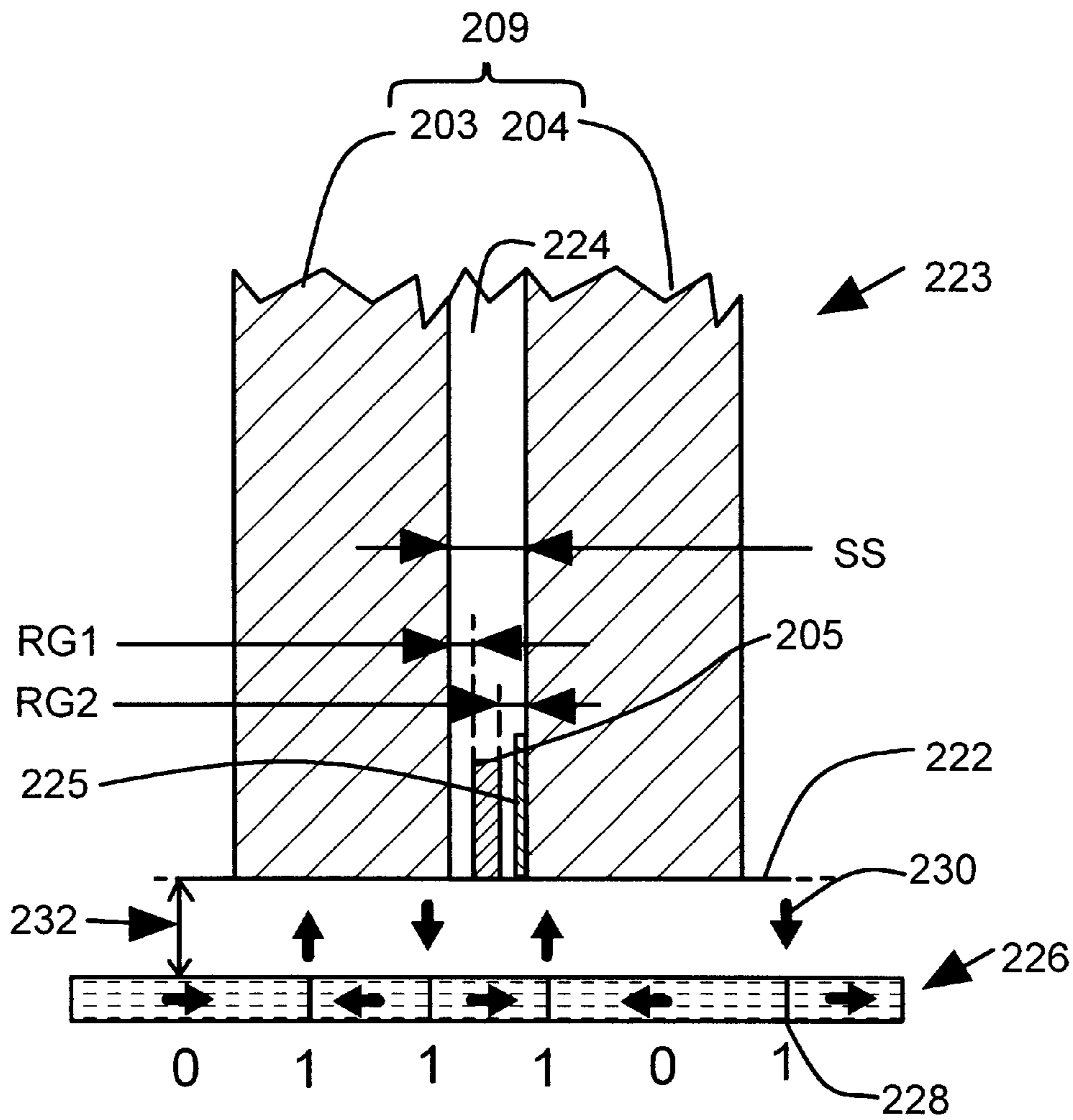


FIG. 4

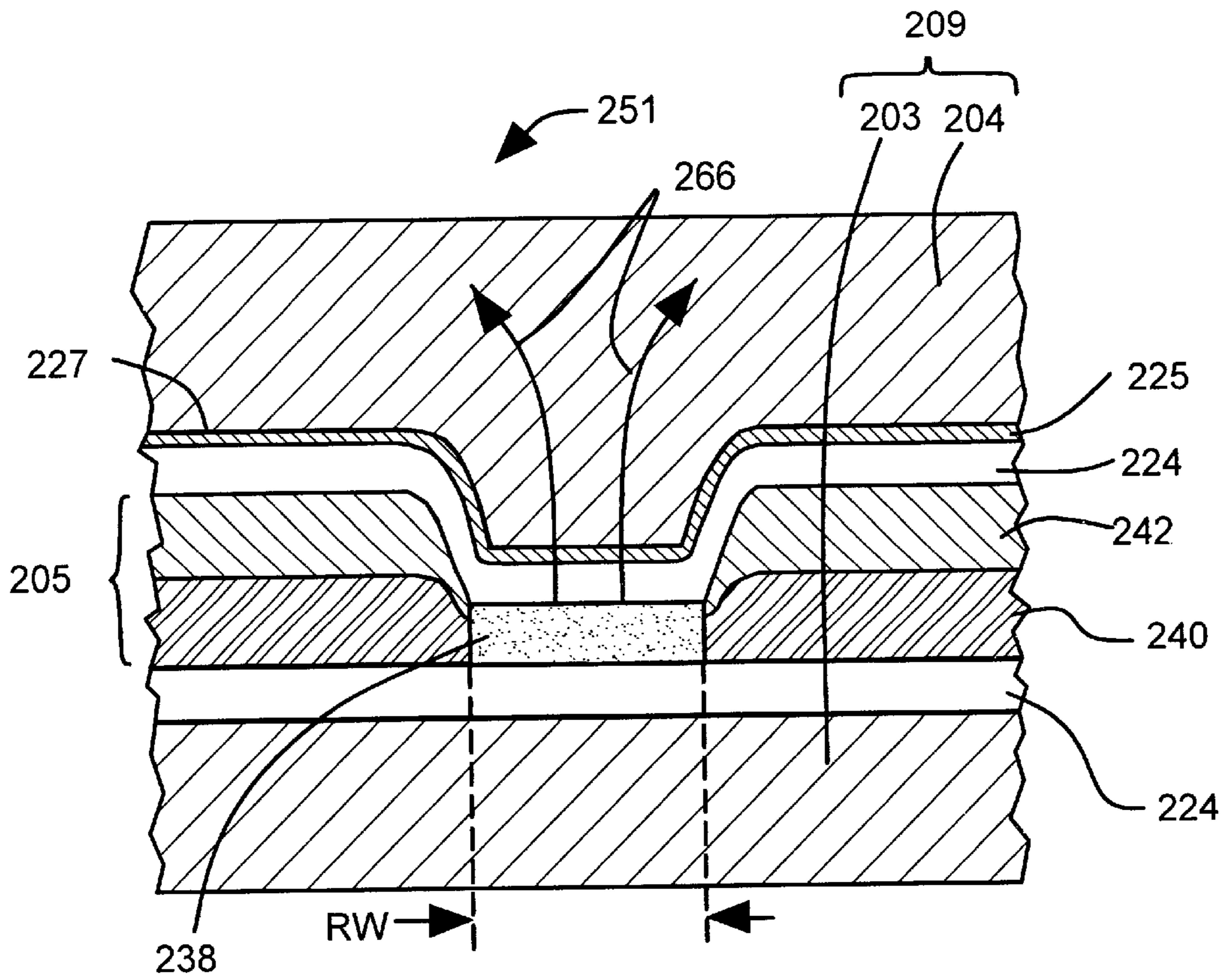
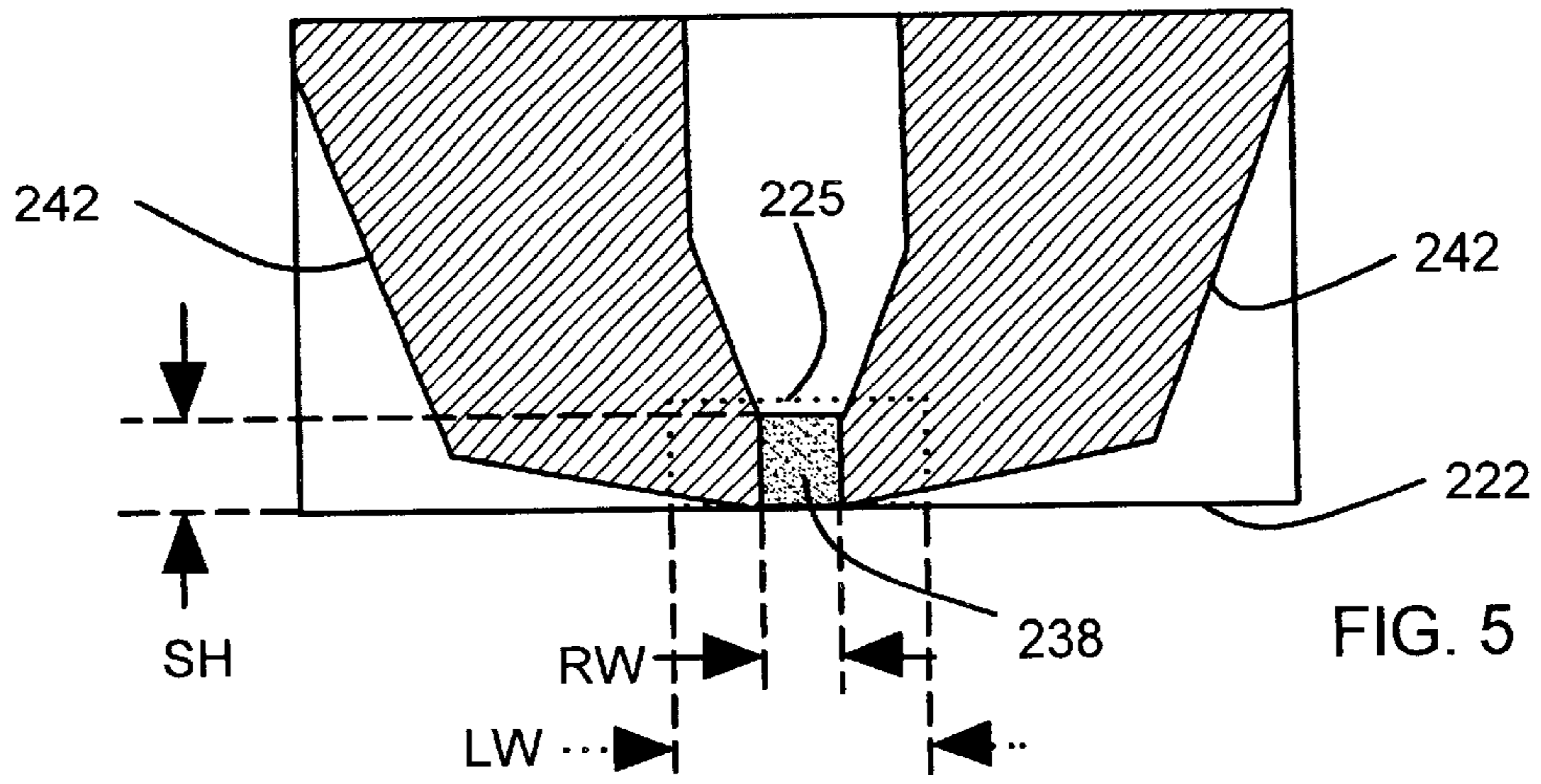


FIG. 6

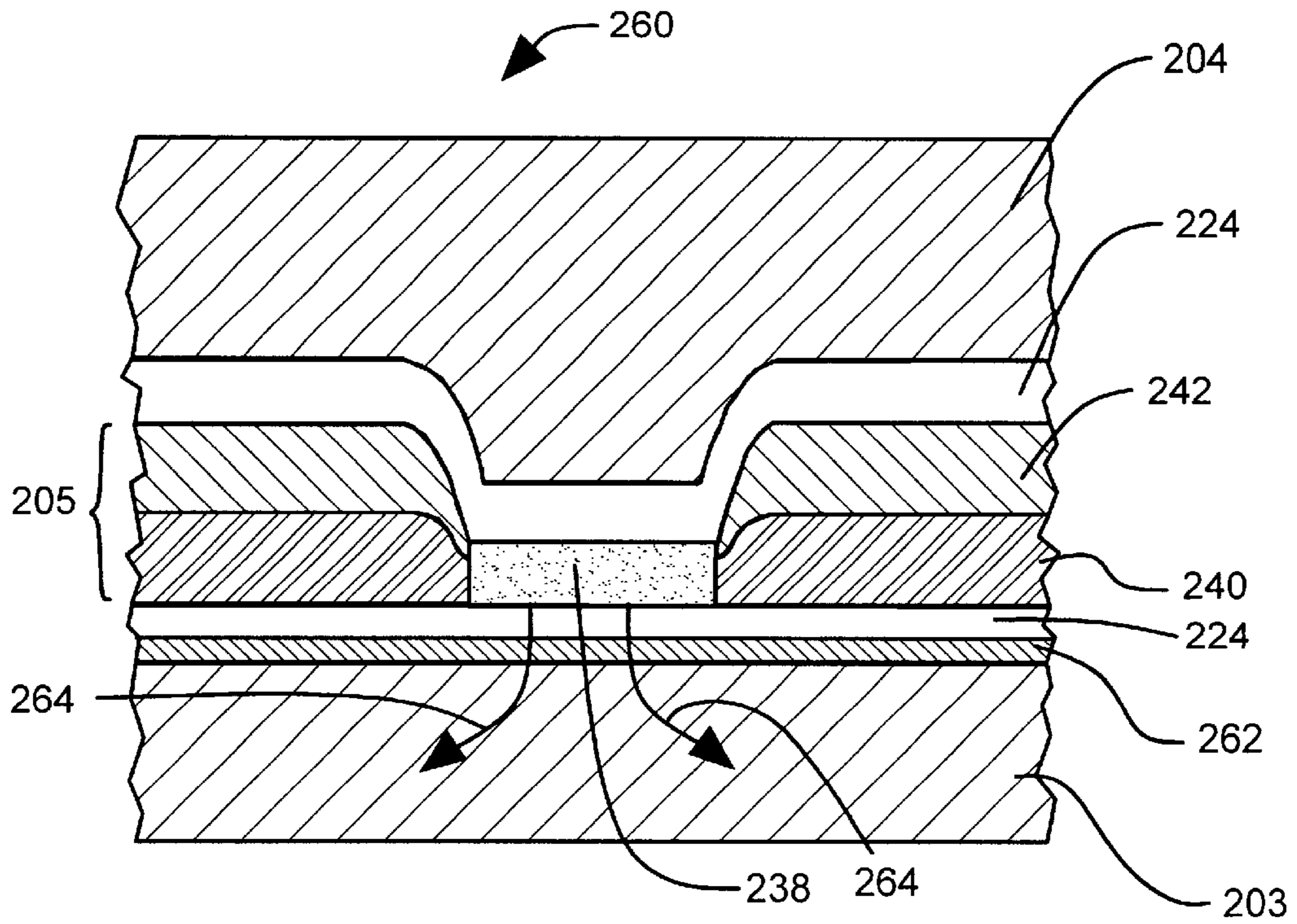


FIG. 7

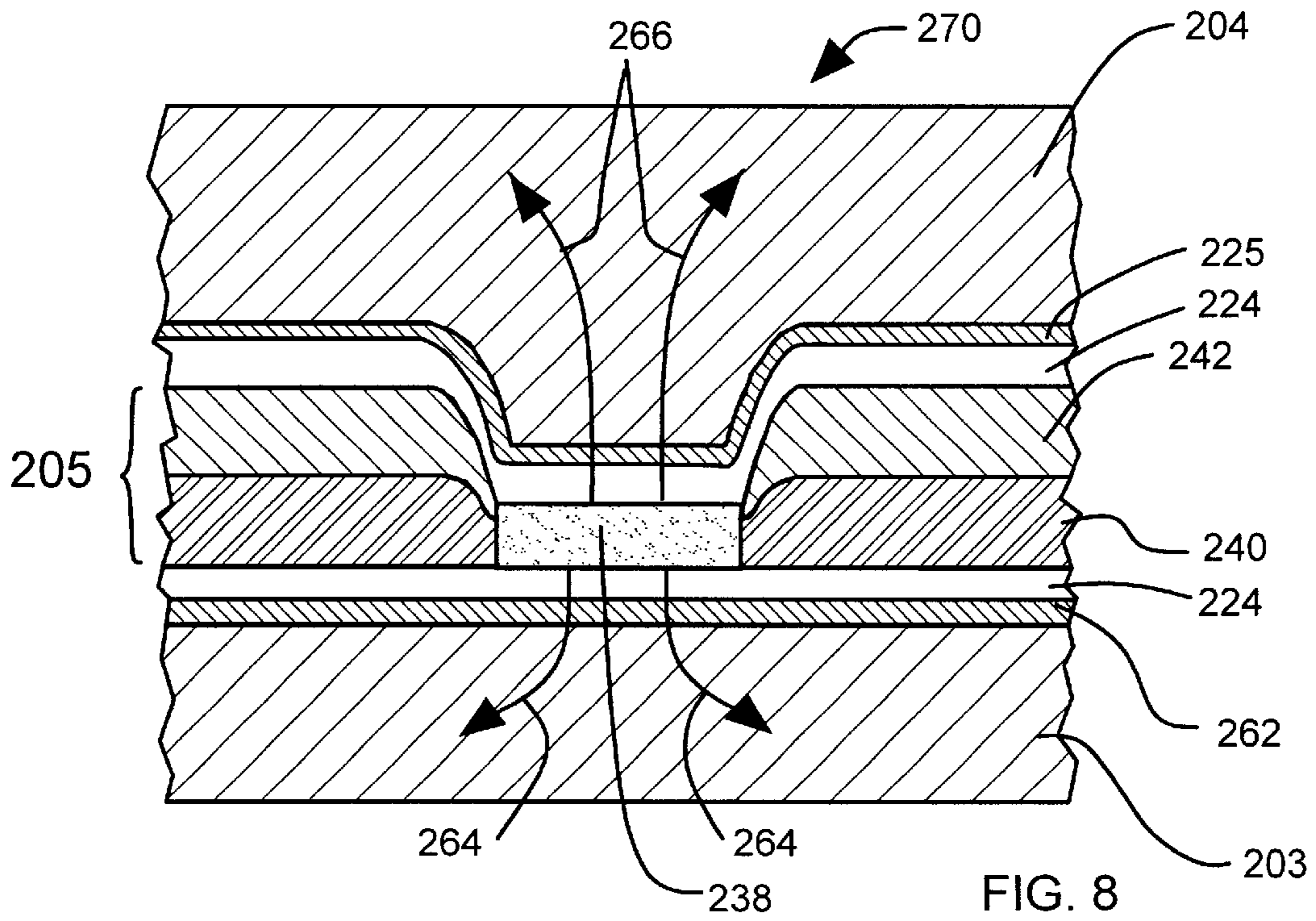


FIG. 8

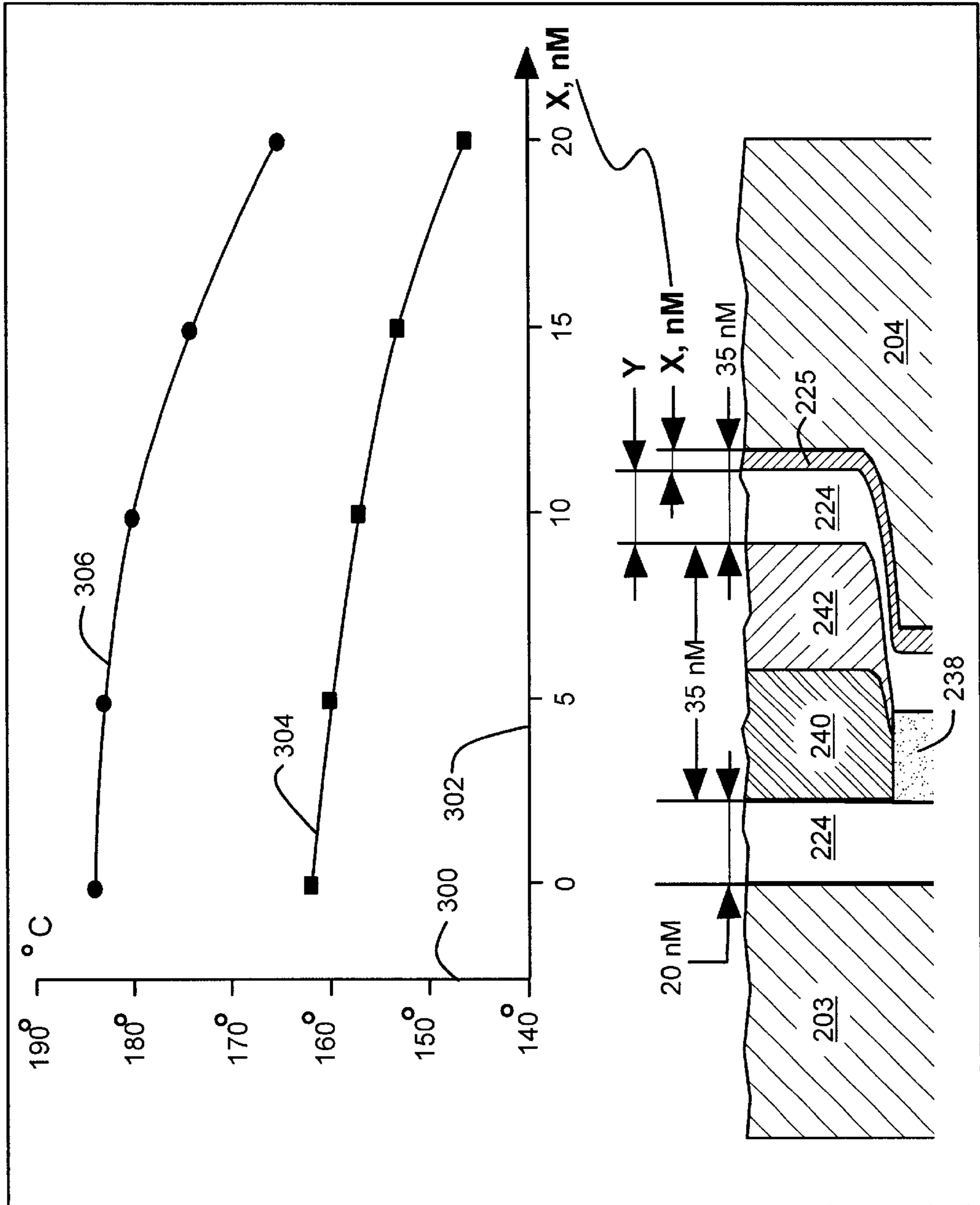


FIG. 9

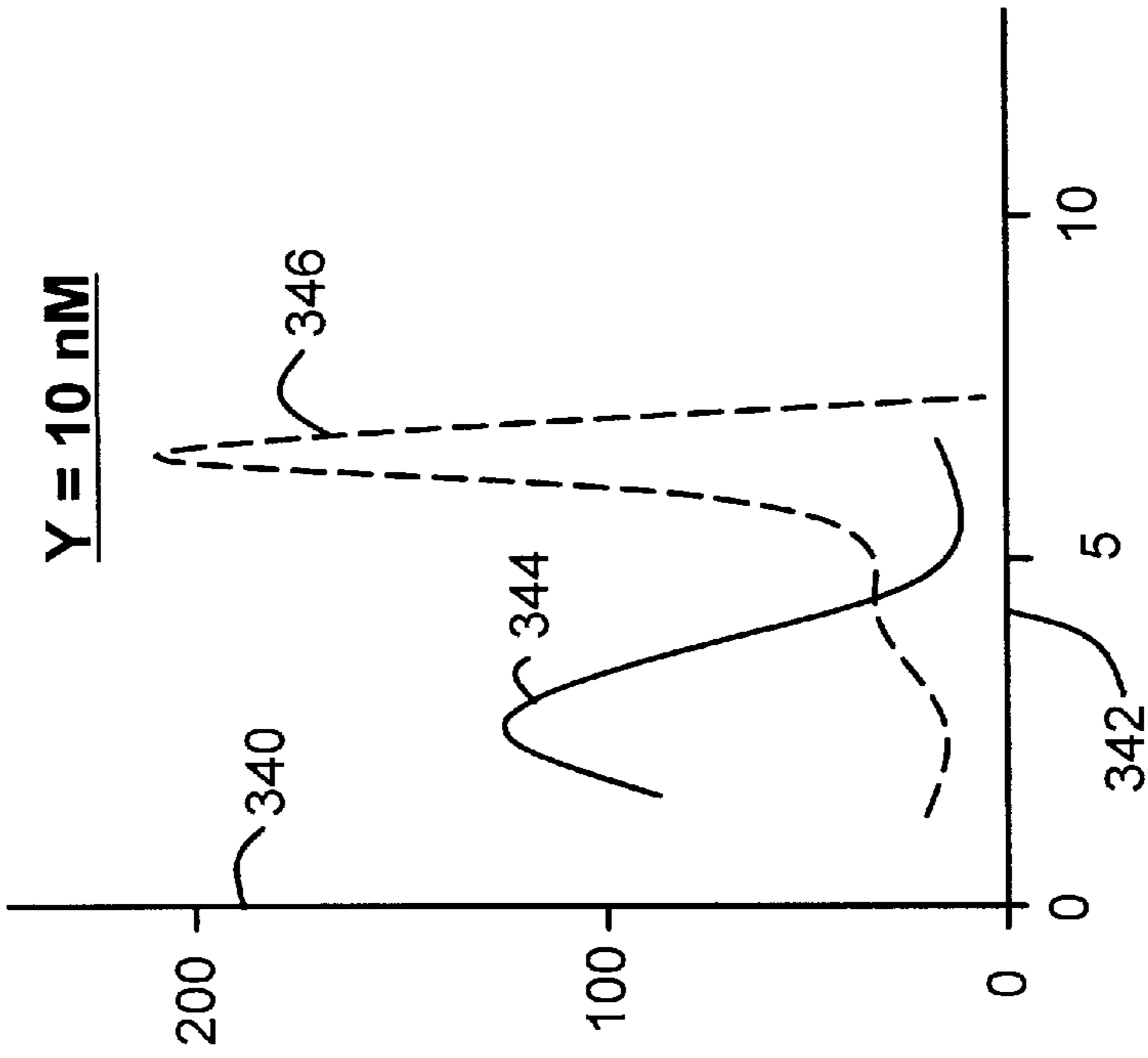


FIG. 11

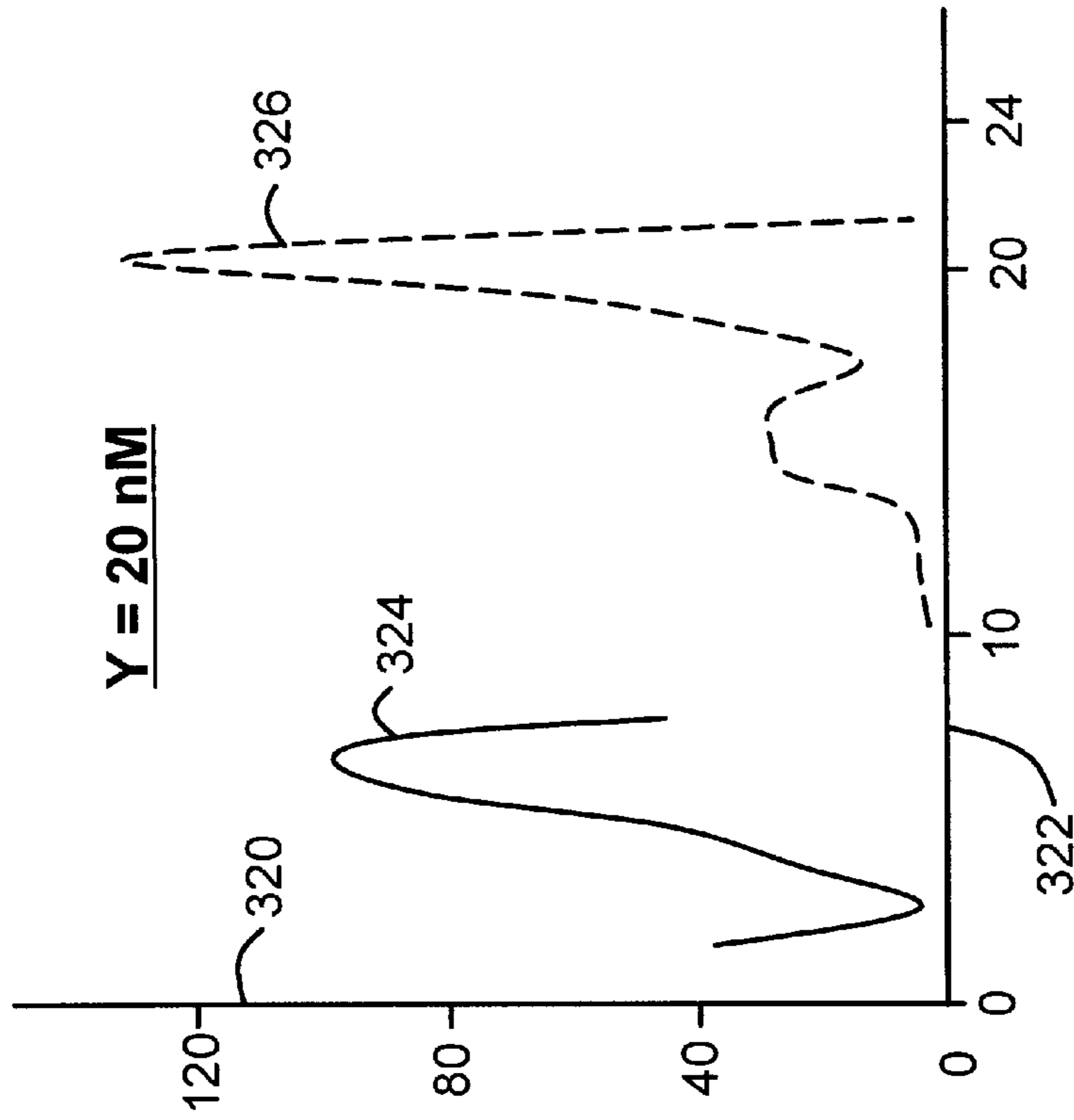


FIG. 10

NON-MAGNETIC METALLIC LAYER IN A READER GAP OF A DISC DRIVE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority benefits from U.S. Provisional Application 60/284,624 titled "Increasing The Read-Back Amplitude In Magnetic Recording Heads by Adding A Nonmagnetic Metallic Layer In The Reader Gap," filed Apr. 18, 2001.

FIELD OF THE INVENTION

The present invention relates generally to heads for use in a magnetic storage drive. In particular, this invention relates to methods and structures for reader gaps.

BACKGROUND OF THE INVENTION

A read/write head in a disc drive typically includes a magnetoresistive (MR) read sensor that is deposited between insulating layers and magnetic shield layers. The magnetoresistive read sensor typically includes a magnetoresistor stack, electrical contacts and one or more bias magnets that magnetically bias the magnetoresistor stack.

The magnetoresistor and electrical contacts carry an electrical bias current. As magnetically stored data on a disc flies by the magnetoresistor, the magnetoresistor generates read-back pulses that have a readback amplitude that represents the data stored on the disc. The readback amplitude is generally proportional to the bias current. The bias current amplitude and read sensor dimensions are chosen in a way that considers the needs of the read channel electronics for a high amplitude readback pulse. The bias current amplitude and read sensor dimensions are also chosen in a way that considers the need to limit heating to prevent damage to the magnetoresistor. The need for a high amplitude readback pulse and the need to limit heating conflict with one another and limit the performance that can be achieved with conventional magnetoresistive read sensors.

As track density on the disc increases, the reader dimensions must be made correspondingly smaller and the conflict between thermal and electrical design requirements increases beyond the capabilities of current designs.

A magnetic read sensor and a method of making such a magnetic read sensor are needed that provide an improved combination of thermal and electrical characteristics in a read/write head usable with higher areal densities.

SUMMARY OF THE INVENTION

Disclosed is a read/write head that comprises a slider substrate and a read shield. The read shield includes a bottom magnetic shield layer on the slider substrate and a shared magnetic shield layer that is spaced apart from the bottom magnetic shield layer.

The read/write head comprises a write head disposed on the shared magnetic shield layer. The read/write head also comprises a read sensor disposed between the bottom magnetic shield layer and the shared magnetic shield layer. The read sensor is spaced apart from the read shield by reader magnetic gaps.

The read/write head also comprises electrically insulating layers on the read sensor. The electrically insulating layers form a thermal resistance between the read sensor and the read shield.

The read/write head also comprises a thermally conducting nonmagnetic layer deposited on the read shield in a first

one of the reader magnetic gaps. The thermally conducting nonmagnetic layer reduces the thermal resistance without a corresponding reduction in the reader magnetic gaps.

These and various other features as well as advantages that characterize the present invention will be apparent upon reading of the following detailed description and review of the associated drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a disc drive storage device.

FIG. 2 illustrates a PRIOR ART arrangement of a magnetoresistive read sensor between shield layers.

FIG. 3 illustrates a cross sectional side view of a thin film read/write head.

FIG. 4 illustrates an enlarged cross sectional side view of a read sensor along with a magnetic layer of a disc.

FIG. 5 illustrates an enlarged partial cross sectional front view of the read sensor in FIG. 4.

FIG. 6 illustrates an enlarged bottom view of the read sensor shown in FIGS. 4-5.

FIG. 7 illustrates an enlarged bottom view of a second embodiment of a magnetoresistive read sensor.

FIG. 8 illustrates an enlarged bottom view of a third embodiment of a magnetoresistive read sensor.

FIG. 9 illustrates peak and average temperatures in a magnetoresistor as a function of a thickness X of a thermally conducting nonmagnetic layer.

FIG. 10 illustrates electrical breakdown failure rates of Y=20 nanometers thick Al₂O₃ layers.

FIG. 11 illustrates electrical breakdown failure rates of Y=10 nanometers thick Al₂O₃ layers.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

In the embodiments described below in connection with FIGS. 3-11, a read/write head provides an improved combination of thermal and electrical characteristics. One or more thermally conducting nonmagnetic layers are included in reader gaps around a magnetoresistive read sensor. These thermally conducting nonmagnetic layers reduce thermal resistance without a corresponding reduction in the reader magnetic gaps. Higher levels of bias current can be applied to the magnetoresistive sensor without overheating the magnetoresistor. The needed level of readback amplitude is achieved without overheating.

FIG. 1 illustrates an embodiment of a disc drive storage device **100**. Disc drive **100** includes a disc pack **126** having storage surfaces **106** that are illustratively layers of material (such as magnetic material or optically readable material). The disc pack **126** includes a stack of multiple discs each accessible by a read/write assembly **112** that includes a read/write head **110**, also called a slider. A spindle motor **127** drives rotation of the discs in disc pack **126** in a direction such as that shown by arrow **107**. As discs are rotated, read/write assembly **112** accesses different rotational locations on the storage surfaces **106** in disc pack **126**. Read/write assembly **112** is actuated for radial movement relative to the disc surfaces **106**, such as in a direction indicated by arrow **122**, in order to access different tracks (or radial positions) on the disc surfaces **106**. Such actuation of read/write assembly **112** is illustratively provided by a servo system that includes a voice coil motor (VCM) **118**. Voice coil motor **118** includes a rotor **116** that pivots on axis **120**. VCM **118** also illustratively includes an arm **114** that supports the read/write head assembly **112**.

Disc drive **100** illustratively includes control circuitry **130** for controlling operation of disc drive **100** and for transferring data in and out of the disc drive **100**.

FIG. **2** illustrates a PRIOR ART arrangement **140** of a read sensor **146**. The illustration in FIG. **2** is a cross-sectional view that faces an air bearing surface flying over a disc such as disc surface **106** in FIG. **1**. The magnetoresistive read sensor **146** includes a magnetoresistor **154** that abuts permanent magnet layers **150** and electrical contacts **152**. The magnetoresistor **154** has a read width RW as indicated in FIG. **2**. Magnetic shield layers **142**, **144** are separated from the magnetoresistor **154** by insulating layers **148** that form reader gaps. A non-planar shape of the magnetic shield layer **142** is the result of process and design constraints. A bias current I passes through electrical contacts **152** and magnetoresistor **154**. A portion of heat dissipated in the magnetoresistor **154** is conducted out of the magnetoresistor **154** through insulating layers **148** to the shield layers **142**, **144**.

When there is a desire to adapt the prior art arrangement **140** to operate at higher areal bit densities, the overall size of the arrangement **140** is reduced to scale the arrangement to work with the higher areal bit density. It is then apparent that the bias current I needs to be reduced in order to avoid overheating the magnetoresistor **154**. After the bias current I is reduced, it is found that the amplitude of the readback pulse is proportionally reduced. In an effort to increase readback pulse amplitude, the thickness of the insulating layers **148** are reduced to reduce thermal resistance between the magnetoresistor **154** and the shields **142**, **144**, which act as heat sinks. With this reduced thermal resistance, the bias current I can be returned to its original level without causing overheating of the magnetoresistor **154**. However, it is then found that the amplitude of the readback pulse is not increased as expected because the shields **142**, **144** are now too close to the magnetoresistor **154** and are excessively shielding the magnetoresistor **154** from magnetic transitions on the disc flying under the magnetoresistor **154**. In addition, it is found that the reduced thickness of the insulating layers **148** has an undesirably high rate of electrical breakdown due to operating voltage differences between the magnetoresistive sensor **146** and the shields **142**, **144**. One of the major modes for electrical breakdown is interlayer diffusion which is thermally driven. Efforts to reduce the size of the arrangement **140** thus reach a limit beyond which it is not practical to make further reductions in size by adjusting the level of the current I and the dimensions of various layers in arrangement **140**. Reader stacks can be redesigned to have higher magnetoresistive ratios, however, this type of reader redesign reaches a limit also. The operating voltage limit of the materials used in insulating layers **148** and the operating temperature limit of the materials used in various layers of magnetoresistor **154** set practical physical limits for areal density performance of the design illustrated in FIG. **2**.

In particular, these physical limits are encountered in an effort to provide an arrangement which have areal densities approaching 50 Gb/inch², 60 k tracks per inch or 700 kb/inch tracks. In terms of the size of the reader arrangement, these physical limits are encountered with shield-to-shield spacing of about 70 nanometers, reader widths of about 220 nanometers or stripe height of about 150 nanometers.

These physical limits are overcome, however, by arrangements explained below in connection with FIGS. **3–11** that include one or more thermally conducting nonmagnetic layers in the reader gaps. These thermally conducting nonmagnetic layers reduce thermal resistance without a corresponding reduction in the reader magnetic gaps. Higher

levels of bias current can be applied to the magnetoresistive sensor without overheating the magnetoresistor. The needed level of readback amplitude is achieved without overheating. Moreover, if problems are encountered with voltage breakdown of a reduced insulating layer, this voltage breakdown problem can be reduced by using atomic layer deposition material in the insulating layer.

FIG. **3** schematically illustrates a partial cross-section of a read/write head **200** for a disc drive. The read/write head **200** includes a thin film read/write head or transducer **214**. The transducer **214** is deposited on a substrate **201**. A large part of the read/write head **200** is built from a substrate **201** that extends to edges **215** and **216** as illustrated. The portion of read/write head **200** that is illustrated in cross-section in FIG. **3** is near the trailing edge of the read/write head **200** along a central plane perpendicular to an air bearing surface **222** of the read/write head **200**.

The substrate **201** is preferably formed from an electrically conducting ceramic material, such as a mixture of aluminum oxide (Al₂O₃) and titanium carbide (TiC), sometimes referred as "AlTiC". Silicon and other known substrate materials can also be used.

A basecoat material **202** is deposited on the top of substrate **201**. The basecoat material **202** is an electrically insulating material, typically Al₂O₃. The basecoat material **202** forms a bond to the substrate material **201**. Silicon dioxide and other known basecoat materials can also be used.

Deposited metallic magnetic layers from alloys of iron (Fe), nickel (Ni), or cobalt (Co) form a bottom magnetic shield layer **203**, shared magnetic shield layer **204**, top pole **212** and a core **206**. Core **206** completes a write magnetic circuit through the center of a coil **208** and through a write gap **220** at the air bearing surface **222**. The core **206**, the coil **208**, the write gap **220** and the coil insulator **207** form a write head **211** disposed on the shared magnetic shield layer **204**. The bottom magnetic shield layer **203** is bonded on the substrate **201** by way of the basecoat material **202**.

The write coil **208** in the transducer **214** is preferably made from copper or from another highly electrically conducting metal or alloy. A coil insulator **207** is typically formed from a cured photoresist. Silicon dioxide and other known coil insulators can also be used.

An additional deposited electrically insulating layer **213** fills the space around bottom magnetic shield layer **203**, and shared magnetic shield layer **204**. A portion of layer **213** (not illustrated in FIG. **3**) also extends between the bottom magnetic shield layer **203** and the shared magnetic shield layer **204** to provide nonmagnetic, electrically insulating layers around a magnetoresistive read sensor **205**. Layer **213** is typically made from Al₂O₃ and forms a bond to the basecoat layer **202**. One or more thermally conductive nonmagnetic metallic layer (shown, for example, in enlarged FIGS. **6–8**) are also arranged around the magnetoresistive read sensor **205**.

For clarity, electrical leads and contacts, formed from Cu, Au, or other metals or metallic alloys in a conventional manner are not illustrated in FIG. **3**.

One or more insulating overcoat or topcoat layers **210** are deposited on the top of all the transducer **214**. Overcoat layer **210** is typically also made from Al₂O₃ or other known dielectrics. Overcoat layer **210** is preferably planarized after deposition to expose electrical contacts (not illustrated) for the coil **207** and the magnetoresistive read sensor **205** in the transducer **214**.

After the read/write head **200** is formed as illustrated in FIG. **3**, it is lapped to precisely shape the air bearing surface (ABS) **222** that flies over the magnetic media.

The read sensor **205** is formed in a very thin layer between the bottom magnetic shield layer **203** and shared magnetic shield layer **204**. Read sensor **205** includes a magnetoresistive (MR) or giant magnetoresistive (GMR) sensor, and comprises multiple layers. The read sensor **205** is arranged with one or more thermally conducting nonmagnetic layers as described below in connection with FIGS. 4–11.

FIG. 4 schematically illustrates an enlarged partial cross sectional view of a read head **223** as illustrated in FIG. 3, and flying above a magnetic layer **226** of a disc such as discs **126** illustrated in FIG. 1. In the read head **223**, a bottom magnetic shield layer **203** and a shared magnetic shield layer **204** are placed on each side of the read sensor **205** and provide magnetic shielding for the read sensor **205**. An insulating layer **224** electrically and magnetically isolates the read sensor **205** from the magnetic shields **203**, **204** with magnetic reader gaps **RG1**, **RG2**. The magnetic reader gaps **RG1**, **RG2** and the thickness of the read sensor **205** make up a shield spacing **SS**. Magnetic reader gap **RG2** also includes a thermally conductive nonmagnetic layer **225** that is deposited on the shared magnetic shield layer **204**. The thermally conductive nonmagnetic layer **225** occupies part of the read gap **RG2** with a material that is nonmagnetic, such that the full magnetic reader gap **RG2** is maintained. The thermally conducting non-magnetic layer **225**, however, is thermally conductive and thus reduces the thermal resistance between the reader **205** and the shared magnetic shield layer **204**. This reduced thermal resistance allows more power to be dissipated in the reader **205** without overheating. The bias current passing through the reader **205** can therefore be higher without causing overheating. The readback amplitude is increased proportional to the bias current and a desired amplitude of readback pulses can be achieved, making the arrangement operable with areal densities that can't be practically achieved with the prior art arrangement shown in FIG. 2.

Read sensor **205** senses external magnetic field components **230** emanating from a track in the magnetic layer **226** as the track flies past the head **223** at a constant speed. The magnetic field components **230** are present over each transition **228** in the magnetic layer **226**. Each transition **228** is a line or wall along which the direction of the magnetization in magnetic layer **226** reverses or changes direction. Each magnetic field component **226** is sensed as it passes between the magnetic shielding layers **203**, **204**. The shielding layers **203**, **204** shield the read sensor **205** from neighboring external magnetic field components **230**. During operation of a disc drive, the head **223** remains spaced away from the magnetic layer **226** by a spacing **232**. The spacing **232** includes an air bearing protective layer and any protective layer that is deposited over the magnetic layer **226**.

Digitized information is stored on the magnetic layer **226** in the form of magnetic transitions **228**. Each bit is represented by the presence (1) or absence (0) of a transition in the media. When transitions **230** are sensed, external electronic circuitry connected to the read sensor **205** interprets the transition **230** as one logical state (a one (1) for example), and interprets the absence of a transition **230** at a particular time as another logical state (a zero, for example). The read sensor **205** produces readback pulses that are coupled to the external electronic circuitry. Various arrangements of the read sensor **205** and shields **203**, **204** with thermally conductive nonmagnetic layers are explained in still more detail below in connection with FIGS. 5–11.

FIG. 5 illustrates a cross-sectional view of the alignment of a magnetoresistor **238** and its associated electrical contacts **242** that are part of the magnetoresistive sensor **205**

shown in FIGS. 3–4. The view illustrated in FIG. 5 is normal to the air bearing surface **222**. FIG. 5 illustrates a read width **RW** of the magnetoresistor **238** and also a stripe height **SH** of the magnetoresistor **238**. The alignment of a thermally conducting nonmagnetic layer **225** is illustrated by a dotted line. The thermally conducting nonmagnetic layer **225** has a layer width **LW** that is parallel to the read width **RW** and that extends beyond the read width **RW** as illustrated.

FIG. 6 illustrates an enlarged bottom view of a portion **251** of the read sensor **223** shown in FIGS. 4–5. The read sensor **223** is part of the read/write head **200** shown in FIG. 3 that includes a slider substrate **201** supporting the bottom magnetic shield layer **203** and a write head **211** disposed on a shared magnetic shield layer **204**. The bottom magnetic shield layer **203** and the shared magnetic shield layer **204** are spaced apart from each other and, taken together, comprise a read shield **209**.

The read sensor **205** is disposed between the bottom magnetic shield layer **203** and the shared magnetic shield layer **204**. The read sensor **205** is spaced apart from the read shield **209** by reader magnetic gaps **RG1** and **RG2** (FIG. 4). Electrically insulating layers **224** on the read sensor provide electrical insulation between the read sensor **205** and the read shield **209**, however, the electrically insulating layers **224** also form an undesired thermal resistance between the read sensor **205** and the read shield **209**.

The thermally conducting nonmagnetic layer **225** is deposited on the read shield **209** in a first one **RG2** of the reader magnetic gaps **RG1**, **RG2**. The thermally conducting nonmagnetic layer **225** reduces the thermal resistance without a corresponding reduction in the reader magnetic gaps **RG1**, **RG2**. As illustrated in FIG. 6 at lines **266**, there is an enhanced heat flow from the magnetoresistor **238** to the shared magnetic shield layer **204** through the thermally conducting nonmagnetic layer **225**.

By using the thermally conductive nonmagnetic layer **225** to replace a portion of an adjacent insulating layer **224**, higher levels of bias current can be applied to the magnetoresistive sensor **205** without overheating the magnetoresistor **238**. The needed level of readback amplitude is achieved without overheating.

In a preferred arrangement, the thermally conducting nonmagnetic layer **225** comprises a metal layer deposited adjacent the read shield **209**. The metal layer preferably comprises tungsten or chromium, which have good corrosion properties and high smearing resistance at the lapped surface **222**. In a further preferred arrangement, a thin seed layer is deposited at the interface **227** between the thermally conducting nonmagnetic layer **225** and the read shield **209**. The thin seed layer is preferably a mixture of metals that match those used in the read shield **209** and the thermally conducting nonmagnetic layer **225**. For example, a seed layer that is a mixture of nickel, iron and tungsten can be used as a seed layer between a tungsten layer **225** and a permalloy layer **204**.

In another preferred arrangement, the electrically insulating layers **224** are atomic layer depositions (ALD) of Al_2O_3 . As explained below in connection with FIGS. 10–11, electrical insulating layers deposited using the ALD process have improved electrical insulation breakdown reliability, allowing thinner layers **224** to be used. In one preferred arrangement, the electrically insulating layer **224** adjacent the thermally conductive nonmagnetic layer **225** has a thickness of 20 nanometers or less. In another preferred arrangement, the electrically insulating layer **224** adjacent the thermally conductive nonmagnetic layer **225** has a

thickness of 10 nanometers or less. In applications where problems are encountered with voltage breakdown of a reduced insulating layer, this voltage breakdown problem can be reduced by using atomic layer deposition (ALD) material in the insulating layer.

FIG. 7 illustrates an enlarged bottom view of a second embodiment of a magnetoresistive read sensor 260 that includes a thermally conducting nonmagnetic layer 262 in a read gap. The arrangement illustrated in FIG. 7 is similar to the arrangement illustrated in FIG. 6 except that in FIG. 7 the nonmagnetic layer 262 is deposited on the bottom magnetic shield layer 203 instead of the shared magnetic shield layer 204. As illustrated in FIG. 7 at lines 264, there is an enhanced heat flow from the magnetoresistor 238 to the bottom magnetic shield layer 203 through the thermally conducting nonmagnetic layer 262.

FIG. 8 illustrates an enlarged bottom view of a third embodiment of a magnetoresistive read sensor that includes a thermally conducting nonmagnetic layer in a read gap. The arrangement illustrated in FIG. 8 is similar to the arrangement illustrated in FIGS. 6-7 except that in FIG. 8 the nonmagnetic layer 262 is deposited on the bottom magnetic shield layer 203, and also the nonmagnetic layer 225 is deposited on the shared magnetic shield layer 204. In FIG. 8, each of the two insulating layers 224 is reduced in thickness to accommodate one of the nonmagnetic layers 225, 262. As illustrated in FIG. 8 at lines 264, 266, there is an enhanced heat flow from the magnetoresistor 238 to the bottom magnetic shield layer 203 through the first thermally conducting nonmagnetic layer 262, and there is also an enhanced heat flow from the magnetoresistor 238 to the shared magnetic shield layer 204 through the second thermally conducting nonmagnetic layer 225.

FIG. 9 illustrates a finite element analysis of peak and average temperatures in a magnetoresistor as a function of a thickness X of a thermally conducting nonmagnetic layer 225 in a head such as the one illustrated in FIG. 6.

In FIG. 9, the vertical axis 300 represents temperature in degrees centigrade and the horizontal axis 302 represents the thickness X in nanometers (nm). A first curve 304 illustrates an average calculated temperature of the magnetoresistor 238 as a function of the thickness X. A second curve 306 illustrates a peak calculated temperature of the magnetoresistor 238. The dimensions used in the finite element analysis model are illustrated at the bottom of FIG. 9. The insulating layer 224 adjacent the bottom shield 203 has a thickness of 20 nm. The read sensor 205 (including the magnetoresistor 238, the bias magnet 240 and the electrical contact 242) has a thickness of 35 nm. The magnetoresistor 238 has a reader width of 250 nm and a stripe height of 150 nm, and the bias current is 4 mA. The thermally conducting nonmagnetic layer 225 has a thickness X which is varied in the finite element analysis. The combined thickness of the thermally conducting non-magnetic layer 225 and the adjacent insulating layer 224 is 35 nm. The insulating layer 224 adjacent the non-magnetic layer has a thickness Y=(35 nm-X) that varies in the finite element analysis. It is found that the results are relatively insensitive to the thermal conductivity of the thermally conducting nonmagnetic layer 225 so long as the layer 225 has a thermal conductivity that is near the thermal conductivity of the shared magnetic shield layer 204. As can be seen from the first curve 304, the average temperature of the magnetoresistor 238 can be reduced up to about 16 degrees centigrade by increasing the thickness of layer 225 up to about 20 nm. As shown by curve 306, the peak temperature can be reduced up to about 20 degrees centigrade by increasing the thickness of layer 225 up to about 20 nm.

FIG. 10 illustrates electrical breakdown failure rates of Y=20 nanometers thick Al₂O₃ layers. FIG. 10 includes a vertical axis 320 representing a rate of insulation breakdown failures per unit time, and a horizontal axis 322 representing a voltage applied across a thickness Y=20 nm of insulation material on a curved surface simulating the shaped surfaces of insulation material 224 in the read sensors illustrated above in FIGS. 6-8. A first curve 324 illustrates a measured rate of insulation breakdown failures for a conventional reactively sputtered Al₂O₃ deposition process. A second curve 326 illustrates a measured rate of insulation breakdown failures for an atomic layer deposition (ALD) process for Al₂O₃. For a voltage difference of 7 volts across the 20 nm layer, for example, the failure rate using conventional reactive sputtering deposition is approximately 100 failures per unit time, while the failure rate using the ALD process is less than 1 per unit time. The ALD process provides very dense, conformal, low leakage current, high breakdown voltage films in the regime around 10 nm thickness. The ALD process has low pinhole density, low impurity concentration and good step coverage, and can be used without a presputter etch.

FIG. 11 illustrates electrical breakdown failure rates of Y=10 nanometers thick Al₂O₃ layers. FIG. 11 includes a vertical axis 340 representing a rate of insulation breakdown failures per unit time, and a horizontal axis 342 representing a voltage applied across a thickness Y=10 nm of insulation material on a curved surface simulating the shaped surfaces of insulation material 224 in the read sensors illustrated above in FIGS. 6-8. A first curve 344 illustrates a measured rate of insulation breakdown failures for a conventional reactive sputtering Al₂O₃ deposition process. A second curve 346 illustrates a measured rate of insulation breakdown failures for an atomic layer deposition (ALD) process for Al₂O₃. For a voltage difference of 2 volts across the 10 nm layer, for example, the failure rate using conventional reactive sputtering deposition is approximately 130 failures per unit time, while the failure rate using the ALD process is less than 10 per unit time.

In summary, a read/write head (110, 200) comprises a slider substrate (201) and a read shield (209). The read shield includes a bottom magnetic shield layer (203) on the slider substrate and a shared magnetic shield layer (204) that is spaced apart from the bottom magnetic shield layer.

The read/write head comprises a write head (211) disposed on the shared magnetic shield layer. The read/write head also comprises a read sensor (223) disposed between the bottom magnetic shield layer and the shared magnetic shield layer. The read sensor is spaced apart from the read shield by reader magnetic gaps (RG1, RG2).

The read/write head also comprises electrically insulating layers (224) on the read sensor. The electrically insulating layers form a thermal resistance between the read sensor and the read shield.

The read/write head also comprises a thermally conducting nonmagnetic layer (225, 262) deposited on the read shield in a first one of the reader magnetic gaps. The thermally conducting nonmagnetic layer reduces the thermal resistance without a corresponding reduction in the reader magnetic gaps.

It is to be understood that even though numerous characteristics and advantages of various embodiments of the invention have been set forth in the foregoing description, together with details of the structure and function of various embodiments of the invention, this disclosure is illustrative only, and changes may be made in detail, especially in

matters of structure and arrangement of parts within the principles of the present invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed. For example, the particular elements may vary depending on the particular application 5 for the read/write while maintaining substantially the same functionality without departing from the scope and spirit of the present invention. For example, additional layers to improve performance can be included and the shapes of features in the read/write head can vary depending on the needs of the application. In addition, although the preferred embodiment described herein is directed to a thin film head for a hard disc drive system, it will be appreciated by those skilled in the art that the teachings of the present invention can be applied to other magnetic systems, like tape drives, 10 without departing from the scope and spirit of the present invention.

What is claimed is:

1. A read/write head comprising:

a slider substrate;

a read shield including a bottom magnetic shield layer on the slider substrate and a shared magnetic shield layer that is spaced apart from the bottom magnetic shield layer;

a write head disposed on the shared magnetic shield layer;

a read sensor disposed between the bottom magnetic shield layer and the shared magnetic shield layer, the read sensor being spaced apart from the read shield by reader magnetic gaps;

electrically insulating layers on the read sensor, the electrically insulating layers forming thermal resistance between the read sensor and the read shield;

a thermally conducting nonmagnetic metal layer comprising a metal selected from the group of tungsten and chromium, the metal layer being deposited on the read shield in a first one of the reader magnetic gaps, the thermally conducting nonmagnetic layer reducing the thermal resistance without a corresponding reduction in the reader magnetic gaps; and

a seed layer bonding the metal layer to the read shield, wherein the seed layer is a mixture of metals including metal matching metal used in the read shield and metal matching metal used in the metal layer.

2. The read/write head of claim **1** wherein the electrically insulating layers are layers of atomic layer deposition of Al_2O_3 .

3. The read/write head of claim **2** wherein the electrically insulating layers include a layer that has a thickness of 20 nanometers or less.

4. The read/write head of claim **3** wherein the electrically insulating layer includes a layer that has a thickness of 10 nanometers or less.

5. A method of manufacturing a read/write head, comprising:

providing a slider substrate;

depositing a bottom magnetic shield layer on the slider substrate and depositing a shared magnetic shield layer that is spaced apart from the bottom magnetic shield layer, the bottom magnetic shield layer and the shared magnetic shield layer forming a read shield;

depositing a write head on the shared magnetic shield layer;

depositing a read sensor between the bottom magnetic shield layer and the shared magnetic shield layer and spacing the read sensor apart from the read shield by reader magnetic gaps;

depositing electrically insulating layers on the read sensor, the electrically insulating layers forming thermal resistance between the read sensor and the read shield;

depositing a seed layer on the read shield, the seed layer being formed from a mixture of metals including metal matching metal used in the read shield and metal matching metal used in thermally conductive nonmagnetic metal layer; and

reducing the thermal resistance without a corresponding reduction in the reader magnetic gaps by depositing the thermally conducting nonmagnetic metal layer on the read shield in a first one of the reader magnetic gaps.

6. The method of claim **5**, further comprising:

forming the electrically insulating layers by a process of atomic layer deposition of Al_2O_3 .

7. The method of claim **6**, further comprising:

forming at least one of the electrically insulating layers with a thickness of 20 nanometers or less.

8. The method of claim **7**, further comprising:

forming at least one of the electrically insulating layers with a thickness of 10 nanometers or less.

9. A read/write head comprising:

a bottom magnetic shield layer on a slider substrate and a shared magnetic shield layer that is spaced apart from the bottom magnetic shield layer, a write head disposed on the shared magnetic shield layer, a read sensor that has read width and that is spaced apart from the read shield by reader magnetic gaps, electrically insulating layers on the read sensor forming thermal resistance between the read sensor and the bottom and shared magnetic shield layers;

means for reducing the thermal resistance without a corresponding reduction in the reader magnetic gaps, the means having a layer width that is parallel to the read width and extends beyond the read width; and

means for forming a seed layer for bonding means for reducing the thermal resistance to the shield layer from a mixture of metals including metal matching metal used in the read shield and metal matching metal used in the means for reducing thermal resistance.

* * * * *